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FREQUENCY DEPENDENCE OF THE ELECTRIC STRENGTH OF DIELECTRICS IN ELECTRICAL BREAKDOWN

A. V. Ryzhenko,[1] N. S. Kostyukov,[1] and V. Kh. Ryzhenko[1]

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It was shown that the dependence of the electric strength of solid dielectrics on the frequency is determined by the corresponding dependence of the dielectric constant and it decreases sharply in the region of dispersion frequencies in elastic oscillations and on relaxation oscillators (in the condition $\omega_0 = 1/\tau$) in relaxation oscillations.

In the electrical form of breakdown, the electric strength is usually not a function of the temperature [1]. The thermal form of breakdown, where the electric strength is a function of the temperature, is observed at high temperatures. For ceramic dielectrics, we know that the region of electrical breakdown can extend to high temperatures, for example, up to 1000°C for aluminous ceramic (microlite), up to 600°C for GB-7 ceramic, and up to 120 – 140°C for high-voltage electrotechnical porcelain. As our studies suggest, thermal breakdown in concretes begins in the 80 – 90°C region (see Fig. 1). At lower temperatures (50°C), electrical breakdown is observed, where the deciding role is played by the local field acting on the charged particle in the dielectric.

The dependence of the electric strength on the local field frequency in polarization processes was examined in [2]. Based on the model proposed by Lorentz, the local field strength E_{loc} is the result of summation of the field strengths:

$$E_{\text{loc}} = E_{\text{av}} + E_1 + E_2 ,$$

where E_1 is the strength of the macroscopic field formed by polarized molecules outside of the Lorentz sphere, equal to $P/(3\varepsilon_0)$, where P is the polarization of the dielectric, equal to $n\alpha E$ (n is the number of atoms with polarizability α; ε_0 is the electric constant, equal to 8.85×10^{-12} F/m); E_2 is the strength of the field created by dipoles located inside the sphere.

The average macroscopic field is determined from the expression:

$$E_{\text{av}} = E_0 - P/\varepsilon_0 ,$$

where E_0 is the strength of the outer field applied to the dielectric.

It is assumed that $E_2 = 0$ for structures of high symmetry and disordered structures. The strength of the local field is thus:

$$E_{\text{loc}} = E_0 - \frac{2P}{3\varepsilon_0} . \quad (1)$$

Then the dipole moment of the unit of volume of a dielectric of complex composition will be described by the expression:

$$P = E_{\text{loc}} \sum_{i=1}^{k} n_i \alpha_i , \quad (2)$$

where k is the number of varieties of polarizable particles.

If we hypothesize that the local field strength at the dielectric point is a measure of the electric strength, the value of $E_s = E_0$ is a quantity determined experimentally from Eqs. (1) and (2) and has the form:

$$E_s = E_{\text{loc}} + \frac{2P}{3\varepsilon_0} = E_{\text{loc}} \left(1 + \frac{2}{3} \frac{\sum_{i=1}^{k} n_i \alpha_i}{\varepsilon_0} \right) = E_{\text{loc}}\, \varepsilon(\omega), \quad (3)$$

where ε is the dielectric constant; ω is the alternating current frequency.

We see from Eq. (3) that the electric strength is proportional to the dielectric constant and decreases with an increase in the frequency. As a consequence, the dependence of the electric strength on the frequency for passive dielectrics such as glass, ceramic materials, and other inorganic dielectrics (concretes) can be analyzed with the frequency depen-

[1] Amur State University, Blagoveshchensk, Russia; Far-East State Agrarian University, Blagoveshchensk, Russia.

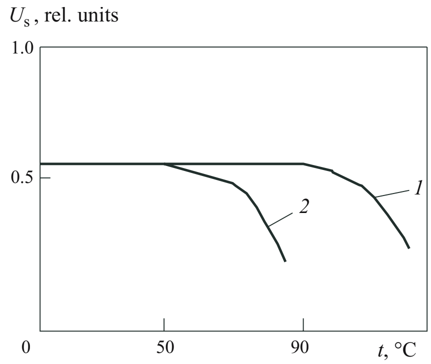

Fig. 1. Temperature dependence of the electric strength of electrotechnical porcelain (*1*) and concrete (*2*).

dence of the dielectric constant and the polarizability α_i of the chemical components in them.

We know that the polarizability, like the dielectric constant, is complex and is described by the equation:

$$\alpha^* = \alpha' + i\alpha'',$$

where α^* is the complex value of the dielectric constant; α' is the real part that determines the dielectric constant; α'' is the imaginary part that determines the dielectric losses; i is an imaginary number.

The oscillations of a particle in the region of the resonance frequency ω_0 in elastic oscillations (visible part, UV and IR region of the spectrum) have a phase shift and α' changes from $\alpha' < 0$ at $\omega > \omega_0$, $\alpha' = 0$ at $\omega_0 = \omega_\mathrm{i}$ to $\alpha' > 0$ at $\omega < \omega_0$ [2] (ω_i is the resonance frequency in the region of the IR spectrum).

The second term in parentheses in Eq. (3) thus changes sign when the frequency passes through the dispersion region and the electric strength passes through a minimum. A similar picture will also be observed in the region of the relaxation frequencies ($\omega < 10^{12}$ Hz), where resonances will be observed in relaxation oscillators when the condition $\omega_0 = 1/\tau$ is satisfied (τ is the duration of relaxation).

Based on these data, we can conclude that the dependence of the electric strength of solid dielectrics on the frequency is determined by the corresponding dependence of the dielectric constant, which decreases sharply in the region of dispersion frequencies in elastic oscillations and in relaxation oscillators (in the condition of $\omega_0 = 1/\tau$) in relaxation oscillations.

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